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RECYCL-3377; No. of Pages 11
ARTICLE IN PRESS

Resources, Conservation and Recycling xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Applications of industrial eggshell as a valuable anthropogenic resource

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ARTICLE INFO

Article history:
Received 17 April 2016
Received in revised form 7 July 2016
Accepted 22 September 2016
Available online xxx

Keywords:
Industrial eggshell
Ca-rich waste
Animal by-product
Valorisation options
Anthropogenic resource

ABSTRACT

Nowadays the European guidelines boost the concept of "circular economy" which is focused on catalysing sustainable development. "Closing the loop" is particularly important for improving the recycling rates, and thus waste and by-products can be turned into a resource with benefits to the economy and environment. Within this scope, this work reviews and updates the potential of valorisation and legal framework of an anthropogenic biomineral with high content of calcium carbonate. Namely, the waste under consideration is the industrial eggshell waste (ES) resulting from egg breakage. This is considered an animal by-product (ABP) and thus some constraints may limit ES applications. The flux of this ABP mainly within the European region is also indicated and the estimated data highlight that significant amount of this biomineral is being produced. Despite legal restrictions, countries such as the UK, Spain and Portugal have been able to find practical application for ES, avoiding landfilling.

The literature shows that applications for industrial eggshell may be grouped into two categories: raw material and operating supply. In the first case, the options are food additive, soil amendment, purified calcium carbonate, cosmetics and biomaterial composite. As operating supply, ES may be used as catalyst and sorbent. Although the economic profit should be evaluated in each case, the environmental benefit of those potential applications is in general high. Considering ES properties and the soil properties in large areas of Europe (acidic pH and low topsoil organic carbon content) the production of Ca-rich compost obtained through composting seems to be a particularly interesting approach toward "circular economy".

1. Introduction

The European Commission has boosted an action plan for promoting the *Circular Economy*, which aims to maintain as long as possible the value of products, materials and resources in the economy, and thus minimising the generation of waste. In this scope, several anthropogenic materials or stocks (considered those resulting from the influence of human beings on nature) are good candidates to be integrated in the context of the circular economy. Similarly to sustainability perspective, also the framework for understanding "circular economy" is a comprehensive approach of three perspectives: environmental impact, resource scarcity and economic benefits (Lieder and Rashid, 2016).

In practice, besides many challenges and barriers to implement this approach (Man and Friege, 2016) it sounds an attractive idea towards sustainable development. Nowadays, hen eggs are one of the most important food resources in the framework of world-wide feeding, since they are an important source of essential nutrients to human diet providing proteins, fat-soluble vitamins (A, D, E and K) and trace-minerals like iron and zinc (Pirvutoiu and Popescu, 2012; Roberts et al., 2005). According to FAO (2016), in 2009 global consumption of eggs rose to 8.9 kg/capita/year (167 eggs[1] consumed per person on an annual basis) which corresponds to an increase of 41% in comparison to the consumption in 1990. As a result of such rise, the egg sector has rapidly expanded, and nowadays the world-wide egg production reaches 6.5×10^7 ton/year, representing 185% of the egg produced in 1990 (FAO, 2016).

Currently the egg sector may be segmented in three levels: production, producer market and consumer market. Most eggs are placed on the consumer market as shell eggs. However, during the past few years the egg-products market has grown significantly, reflecting the increasing consumer demand for liquid, frozen, concentrated or dried powder eggs. Indeed, the egg processing industry

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[1] Using a conversion rate of 54 g per egg (FAO, 2016).

http://dx.doi.org/10.1016/j.resconrec.2016.09.027
0921-3449/

Please cite this article in press as: Quina, M.J., et al., Applications of industrial eggshell as a valuable anthropogenic resource. Resour Conserv Recy (2016), http://dx.doi.org/10.1016/j.resconrec.2016.09.027

Table 1
Estimated annual ES production by the hen egg processing industry in 2011 and 2013 for some countries.

Country	Egg production (thousand tonnes)[a]		Egg for processing (thousand tonnes)[b]		Eggshell waste (thousand tonnes)[c]		GDP growth[d] (%)	
	2011	2013	2011	2013	2011	2013	2011	2013
Canada	436.8	442.8	131.1	132.8	14.4	14.6	2.96	2.00
USA	5419.4	5636.2	1083.9	1127.3	119.2	124.0	1.60	2.22
France	839.5	944.0	251.9	283.2	27.7	31.2	2.08	0.66
Germany	777.1	892.8	233.1	267.8	25.6	29.5	3.66	0.30
Italy	736.8	775.0	221.0	232.5	24.3	25.6	0.59	−1.75
Portugal	122.8	125.5	29.5	30.1	3.2	3.3	−1.83	−1.13
Spain	830.0	742.6	249.0	222.8	27.4	24.5	−1.00	−1.67
United Kingdom	662.0	672.0	115.5[e]	98.6[e]	11.2	10.8	1.97	2.16
All European countries	10638.6	10933.3	3191.6	3280.6	351.1	360.8	–	–

[a] data according to FAO (2016).
[b] Egg for processing = Egg production x Processing factor; processing factor equals 0.3 for Canada (Global Poultry Trends, 2011) and France, Germany, Italy, Spain (Agra CEAS Consulting Ltd, 2008); 0.24 for Portugal (Agra CEAS Consulting Ltd, 2004); 0.2 for USA (Global Poultry Trends, 2011).
[c] Eggshell waste = Egg for processing x% mass shell in egg; % mass shell in egg = 11% (Meski et al., 2011; Oliveira et al., 2013).
[d] GDP: gross domestic product; data according to World Bank (2016).
[e] data from UK egg processing values (DEFRA - Department for environment food and rural affairs, 2013).

is very competitive and offers a wide range of products. Regardless of the egg product obtained, waste generation in egg breaking operations is mainly associated with eggshell (ES) obtained from processing the raw material (shell eggs). Russ and Meyer-Pittroff (2004) indicate that ES represents 3 to 12% of the egg mass product obtained, depending on the egg shell properties (size and shell thickness).

Considering the amount of ES produced worldwide, this paper addresses several related topics with the aim of discussing and identifying practical applications, addressing as much as possible the environmental impact concerns and resource scarcity. Firstly, an overview about the egg processing industry and eggshell production is given. Then, some eggshell properties are summarized to figure out the potential applications. Afterwards, the European legal framework that states the acceptable possibilities to protect public and animal health as well as to reduce environmental risk is thoroughly revised. Lastly, a comprehensive overview about the potential valorisation options for eggshell is presented, including a comparative assessment. Particular emphasis will be given to the possibility of "closing the loop" by co-composting ES and producing a compost for soil amendment with good acid neutralization capacity."

2. The egg processing industry and eggshell production

In general, processing industry receives eggs packaged in cartons from distributors and stores them in a cool and humid atmosphere for preservation until utilisation. After unpacking, inspection is performed to detect leaking broken shells and eggs of poor interior quality (e.g. developed embryos, etc.). Washing is performed with detergents and defoaming agents to remove any contaminant from shell surface. Washed eggs are often rinsed with sanitising agents (Cotterill and McBee, 1995). Egg breaking and separation of shell from liquid content are performed by automated machines and further processing phases of the liquid egg depend on the desired final product (liquid, frozen, concentrated or dried powder eggs). The eggshell waste still contains membrane and remains of white and yolk, and thus leaching liquids and unpleasant odour are easily released.

Presently, available data with respect to annual industrial production of ES is scarce and it was estimated as indicated in Table 1. According to this data one may conclude that a significant amount is being produced in egg breaking industries.

The European Union countries mentioned in Table 1 (France, Germany, Italy, Portugal, Spain and UK) produce about 34% of the total value estimated for eggshell generated in Europe. Portugal is the smallest contributor due to its lower egg production capacity. In spite of the reduction of the gross domestic product (GDP) that took place in some countries (e.g. France, Germany, Italy and Spain) only in Spain ES waste production was in-line with an economic retraction pattern. Reduction of private consumption of eggs might be the main aspect that contributed to this development tendency.

Table 2
Industrial ES waste characterization (Soares et al., 2015).

Parameters	*ES*
Moisture (%)	1.0
pH	8.3 ± 0.1
EC ($dS\,m^{-1}$)[a]	0.45
Equivalent $CaCO_3$ (g $CaCO_3$ 100 g $_{airdried}{}^{-1}$)	88 ± 0
Organic matter (%)	6.3± 0.1
TOC/TN	2.1
Germination index (%)[b]	53.6 ± 3.3
Respiration rate (mg C-CO_2 g^{-1}C d^{-1})	24 ± 1
Pb $_{aquaregia}$ (mg kg^{-1})	3.6 ± 0.0
Zn $_{aquaregia}$ (mg kg^{-1})	5.0 ± 0.1

[a] EC: electrical conductivity.
[b] In aqueous extract with *Lepidium sativum*.

Globally, the development of adequate management strategies for this product-specific waste has been considered a challenge for the food industry in what concerns environmental protection, due to not only the large amounts generated but also for its potential for microbial proliferation or pathogens growth (Russ and Schnappinger, 2007; Kim et al., 2016). In addition, also the economic aspect related to eggshell disposal is of great concern, since it has become increasingly costly. Then the development of value-added applications for ES would be both environmentally and financially beneficial.

3. Eggshell properties

Eggshell is a biomineralized composite of calcite crystals embedded in an organic framework of protein fibres, that represents about 11% of the total weight of the egg (Meski et al., 2011; Oliveira et al., 2013). This macroporous structure contains open voids with a similar total volume of 0.006 $cm^3\,g^{-1}$ and BET surface area ranged between 0.84 ± 0.3 to 1.3 ± 0.4 $m^2\,g^{-1}$ (Ehrampoush et al., 2011; Gao and Xu, 2012; Tsai et al., 2006). Some of the properties of industrial ES waste determined in a previous study are reported in Table 2. It is clear that ES is an alkaline and nitrogen rich material, with high content of $CaCO_3$ and low percentage of organic matter (close to 6% (w/w)).